

The Impact of Genetically Engineered Crops on Farm Sustainability in the United States

Corn, cotton, and soybean that have been engineered to resist insect pests and herbicides are now planted on almost half of all U.S. cropland. An analysis of the U.S. experience with genetically engineered crops shows that they offer substantial net environmental and economic benefits compared to conventional crops; however, these benefits have not been universal, some may decline over time, and potential benefits and risks may become more numerous as the technology is applied to more crops. Understanding the impacts of genetically engineered crops is vital to ensuring that crop-management practices and future research and development efforts realize the full potential of genetic engineering for commercial as well as public goods purposes, while maintaining the environmental, economic, and social sustainability of U.S. farms.

With the advent of genetic-engineering technology in agriculture, the science of crop improvement entered a new realm. Advances in molecular and cellular biology now allow scientists to introduce desirable traits from other species into crop plants through genetic engineering. The ability to transfer genes between species is a leap beyond crop improvement through previous plant-breeding techniques, which could transfer desired traits only between related types of plants.

The most commonly introduced genetically engineered (GE) traits allow plants either to produce their own insecticide, reducing crop losses to insect damage, or to resist herbicides, so that herbicides can be used to kill many types of weeds without harming crops. Those traits have been incorporated into most varieties of soybean, corn, and cotton grown in the United States. Since their introduction in 1996, the use of GE crops has grown rapidly and accounted for over 80 percent of soybean, corn, and cotton acreage in the United States in 2009.



Corn earworm, a common pest.

Source: Clemson University—USDA Cooperative Extension Slide Series, Bugwood.org

Studies show that when best management practices are implemented, GE crops have been effective at reducing pest problems with economic and environmental benefits to farmers. Genetic engineering could potentially be used in more crops, in novel ways beyond herbicide and insect resistance, and for a greater diversity of purposes. For

example, GE crops could help address global food insecurity through the development of plants with improved nutritional qualities or resilience to a changing climate.

This National Research Council report provides the first comprehensive assessment of the effects of the GE-crop revolution on farm-level sustainability in terms of environmental, economic, and social impacts on both the farms that adopt GE crops and those that do not. It details the challenges and opportunities for future GE crops and offers recommendations on how crop-management practices and future research and development efforts can help to realize the full potential offered by genetic engineering.

The Most Common GE Traits in United States Agriculture

Resistance to herbicides, insects, and viruses has been genetically engineered into only a few crops in the United States. Nevertheless, GE crops have a high profile because herbicide-resistant and insect-resistant traits are incorporated into three of the most widely grown crops in the United States: soybean, corn, and cotton. Almost half of U.S. cropland in 2009 was planted to a GE variety of one of these crops.

Most herbicide-resistant crops are resistant to the herbicide glyphosate. Glyphosate kills most plants without substantial adverse effects on animals or on soil and water quality, unlike some other classes of herbicides. Because the crops are resistant to the chemical, glyphosate can be applied to kill weeds both before and after the crops emerge from the soil.

Insect-resistant crops contain toxins from a soil-dwelling bacterium, *Bacillus thuringiensis* (Bt). The Bt toxins are lethal to the larvae of particular species of moths, butterflies, flies, and beetles, but are harmless to humans, animals, or types of insects not susceptible to the toxin. The toxins are effective only when a susceptible insect feeds on the plant.

Environmental Effects of GE Crops

Adoption of herbicide-resistant crops could help improve soil and water quality

Farmers have traditionally tilled fields to disrupt weeds, but tilling can erode and compact soil, reducing its ability to absorb water and leading to runoff that can pollute rivers with sediments and chemicals. The use of herbicide-resistant crops allows farmers to apply herbicides to the field to remove weeds after crops emerge from the soil, reducing the need to till and benefiting soil and water quality. Given that runoff from agriculture is the largest source of surface water pollution in the United States, this could represent the largest single environmental benefit of GE crops, but the infrastructure to track and analyze these effects is not in place.

Reliance on one herbicide reduces the effectiveness of herbicide resistance as a weed-management tool

Because herbicide-resistant crops resist glyphosate, farmers who plant GE crops often use this herbicide exclusively. However, the repeated use of glyphosate as the only weed-management strategy favors the evolution of glyphosate-resistant weeds. It also allows weeds that already have a natural resistance to glyphosate to thrive in fields with herbicide-resistant crops. Eventually, repeated use

will render glyphosate ineffective. To limit the evolution of glyphosate-resistant weeds, farmers of herbicide-resistant crops should incorporate more diverse management practices, such as herbicide rotation and tank-mixes of more than one herbicide. In addition, new genetically engineered herbicide-resistant crops are currently under development which may provide growers with other weed-management options.

Targeting specific insect pests with Bt toxins in corn and cotton has been successful, and insecticide use has decreased with the adoption of insect-resistant crops

Unlike broad-spectrum insecticides that kill most insects, even beneficial ones such as honey bees or natural predators of pests, crops producing Bt toxins target only the specific pests that feed on the crops. Repeated plantings of Bt crops could lead to the emergence of Bt-resistant insects, but a successful refuge strategy mandated by the U.S. Environmental Protection Agency has prevented this from occurring so far. The strategy mandates a certain percentage of every Bt field must be planted with non-Bt seed to ensure that a population of insects susceptible to Bt toxin will survive. The introduction of multiple Bt toxins in new crop varieties further reduces the probability of insect resistance to Bt crops.

The transfer of GE traits from GE crops to other crops or relatives has not been a concern for most non-GE crops

There is the possibility that GE traits could be transferred via wind or insect pollination to related species, but this is only a concern for the species, such as cotton and sugar beet, which actually have wild or weedy relatives in the United States; corn and soybean do not. Gene transfer could be limited by planting restrictions to ensure that adequate space is left around fields of GE crops to prevent wind or insect pollination of nearby related species. How gene flow between GE varieties and non-GE relatives is managed in the future will depend on what GE crops are commercialized and whether related species with which they can interbreed are present. For farmers who produce food for markets that prohibit GE material, gene flow of approved GE traits into non-GE crops remains a serious concern.

Economic Effects of GE Crops

Many adopters of GE crops have experienced either lower costs of production or higher yields, and sometimes both

Many farmers who use GE crops have experienced more cost-effective weed control and reduced losses from insect pests. Farmers who previously

faced high levels of insect pests that were difficult to treat before insect-resistant crops have particularly benefitted from applying lower amounts of or less expensive insecticides. More effective management of weeds and insects also means that farmers may not have to apply insecticides or till for weeds as often, translating into lower expenditures for pesticides and less labor and fuel for equipment operations.

Farmers value increased worker safety and greater simplicity and flexibility in farm management

Studies show that the high rates of adoption of GE crops can be attributed in part to the value farmers place on increased worker safety, the perceived greater flexibility in farm management, and the lower production risk associated with the crops. Farmers and their employees not only face reduced exposure to the harsh chemicals found in some herbicides and insecticides used before the introduction of GE crops, but also spend less time in the field applying the pesticides.

The economic effects of GE crops on farmers of conventional crops are poorly understood

The decisions to adopt GE crops can have far-reaching effects on other farms—for example, livestock producers constitute a large percentage of corn and soybean buyers for feed and therefore are major beneficiaries of a reduction in crop price that might result from an expanded feed supply due to better yields from GE crops. However, there has been no quantitative estimation of savings to livestock producers due to the adoption of GE crops, or of the resulting effect on the profitability of livestock operations.

To the extent that genetic-engineering technology successfully reduces pest pressure on a field and regionally, farmers of fields planted with non-GE crops may benefit from lower pest-control costs associated with reductions in pest populations. However, farmers who do not use genetic-engineering technology also could suffer from the development of weeds and insects that have acquired pesticide resistance in fields planted to GE crops. Similarly, if GE traits were to cross into weedy relatives, it is possible that weed-control expenses could be higher for all fields on to which the weeds spread, whether a farmer grows GE crops or not.

Gene flow of GE traits into non-GE crops has the potential to jeopardize crop value by rendering outputs unsuitable for high-value foreign or other markets that limit or do not permit GE material in food products, though the extent of that effect has not been documented during the last 5 years. On the other hand, the segregation of GE traits from organic production may have benefited organic producers by creating a market in which they can receive a premium for non-GE products.

Social Effects of GE Crops

GE crops may have social impacts similar to previous technological developments in agriculture

Research on earlier technological developments in agriculture suggests that there are likely to be social impacts from the adoption of GE crops. For example, it is possible that farmers with less access to credit or those who grow crops for smaller markets would be less able to access or benefit from GE crops. The introduction of genetic-engineering technology in agriculture could affect labor dynamics, farm structure, community viability, and farmers' relationships with each other, but the extent of the social effects of GE crops are poorly understood because there has been little research on the topic to date.

Ongoing research is needed to investigate how market structure may affect access to and the development of GE traits

The U.S. seed industry has evolved from small, family-owned businesses to a market dominated by a handful of large, diversified companies. These companies have invested significantly in the research, development, and commercialization of patent-protected GE traits for the large seed markets of corn, soybean, and cotton, but have so far chosen not to commercialize GE traits in many other crops, either because the market size is insufficient to cover the necessary research and development costs, or due to concerns about consumer acceptance of the crops and the risk of transfer of GE traits to other plants. Universities and public research institutions could help develop alternative crops for smaller markets, but full access to state-of-the-art technology developed by the large seed companies is often not available due to patent protections.



With respect to commercialized GE crops, studies conducted in the first few years after the introduction of GE crops found no adverse effects on farmers' economic welfare from the consolidation of market power in the seed industry. However, the current developmental trajectory of GE-seed technology towards multiple stacked traits is causing some farmers of soybean, corn, and cotton to express concern that access to seeds without GE traits or to seeds that have only the specific GE traits that are of particular interest to farmers will become increasingly limited.

Recommendations

- Public and private research institutions should allocate sufficient resources to monitor and assess the substantial environmental, economic, and social effects of current and emerging agricultural biotechnology on U.S. farms so that technology developers, policymakers, and farmers can make decisions that ensure genetic engineering contributes to sustainable agriculture.
- Federal and state government agencies, private-sector technology developers, universities, farmer organizations, and other relevant stakeholders should collaborate to document emerging weed-resistance problems and to develop cost-effective resistance-management programs and practices that preserve effective weed control in herbicide-resistant crops.
- The U.S. Geological Survey and companion federal and state environmental agencies should receive the financial resources necessary to document the water quality effects related to the adoption of GE crops.
- Public and private research institutions should be eligible for government support to develop GE crops that can deliver valuable public goods but have insufficient market potential to justify private investment. Intellectual property patented in the course of developing major crops should continue to be made available for such public goods purposes to the extent possible. Furthermore, support should be focused on expanding the purview of genetic-engineering technology in both the private and public sectors to address public goods issues. Examples of GE-crop developments that could deliver such public goods include but are not limited to:
 - plants that reduce pollution of off-farm waterways through improved use of nitrogen and phosphorus fertilizers,
 - plants that fix their own nitrogen and reduce pollution caused by fertilizer application,
 - plants that improve feedstocks for renewable energy,
 - plants with reduced water requirements that slow the depletion of regional water resources,
 - plants with improved nutritional quality that deliver health benefits, and
 - plants resilient to changing climate conditions.

The Committee on The Impact of Biotechnology on Farm-Level Economics and Sustainability: David E. Ervin, (Chair), Portland State University; Yves Carrière, University of Arizona; William J. Cox, Cornell University; Jorge Fernandez-Cornejo, Economic Research Service, U.S. Department of Agriculture; Raymond A. Jussaume, Washington State University, Pullman; Michele C. Marra, North Carolina State University; Micheal D. K. Owen, Iowa State University; Peter H. Raven, Missouri Botanical Garden; L. LaReesa Wolfenbarger, University of Nebraska, Omaha; David Zilberman, University of California, Berkeley; Kara N. Laney (Study Director), National Research Council.

The National Academies appointed the above committee of experts to address the specific task requested by the National Research Council. The members volunteered their time for this activity; their report is peer-reviewed and the final product signed off by both the committee members and the National Academies. This report brief was prepared by the National Research Council based on the committee's report.



For more information, contact the Board on Agriculture and Natural Resources at (202) 334-3062 or visit <http://nationalacademies.org/banr>. Copies of *The Impact of Genetically Engineered Crops on Farm Sustainability in the United States* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; www.nap.edu.

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